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PROJECT IMPACT SEATTLE
BUILDING A DISASTER RESISTANT COMMUNITY

Early Warning of Landslides Around Puget Sound, Washington

Why worry about landslides?

When wet winter weather sets in, many residents of the Puget Sound area begin to worry about landslides. Landslides that occur on bluffs and hillsides of communities surrounding Puget Sound, Washington, pose a serious hazard to people, property, utilities, transportation, and businesses (fig. 1). Landslides occur almost every year during the wet season, which usually lasts from October through April. Major winter storms have caused many destructive landslides. For example, four people perished and economic losses throughout the area totaled hundreds of millions of dollars as a result of landslides caused by storms during the winter of 1996–'97. Consequently, in an effort to improve emergency preparedness for landslides, the U.S. Geological Survey in partnership with the City of Seattle, has developed methods that can be used to forecast the occurrence of landslides.

Figure 1. Workers remove debris deposited by a January 1997 landslide in the Magnolia Bluff area of Seattle (Photograph by Alan Chleborad, USGS). Destructive landslides are a common occurrence in Seattle during prolonged or intense winter rainfall. Forecasting landslide occurrence and providing early warning is one way to reduce the hazard from landslides.

Forecasting landslides

Specific landslides are very hard to predict even with sophisticated sensors and models. Notably most landslides around Puget Sound occur during periods of wet weather between October and April, so it is possible to know when landslides are more likely to occur. Scientists at the USGS have developed methods and formulas based on past rainfall amounts to identify when landslide occurrence is likely. These formulas are called "precipitation thresholds". Two thresholds have been developed for the Seattle area. The first one, called the Cumulative Precipitation Threshold (fig. 2), tracks precipitation over the last 18 days and indicates when the ground is wet enough to be susceptible to landslides. The second, called the Intensity-Duration Threshold (fig. 3), tracks rainfall during a storm and tells when it is raining hard enough to cause multiple landslides.

Do the precipitation thresholds predict all landslides?

No, about 15% of landslides between 1978 and 2003 occurred on days when precipitation amounts were below the Cumulative Precipitation Threshold. Some landslides show a delayed response to heavy or prolonged precipitation and others occur without any obvious triggering event. One recent disastrous landslide event in the Seattle area occurred in part from melting snow (January 1997). Neither threshold specifically accounts for snowmelt, so additional factors must be considered when snow is on the ground. Also, the thresholds do not predict landslides caused by earthquakes or construction activities.

Is it possible to distinguish storms that will cause tens or hundreds of landslides from those that will cause only a few?

Rainfall amounts that are well above the thresholds are more likely to cause large numbers of landslides, but there is no clear separation between storms that caused tens of landslides from those that caused only a few (fig. 3). The larger the area affected by a winter storm that exceeds the thresholds, the more likely there will be a large number of landslides. Monitoring the soil wetness and soil pore-water

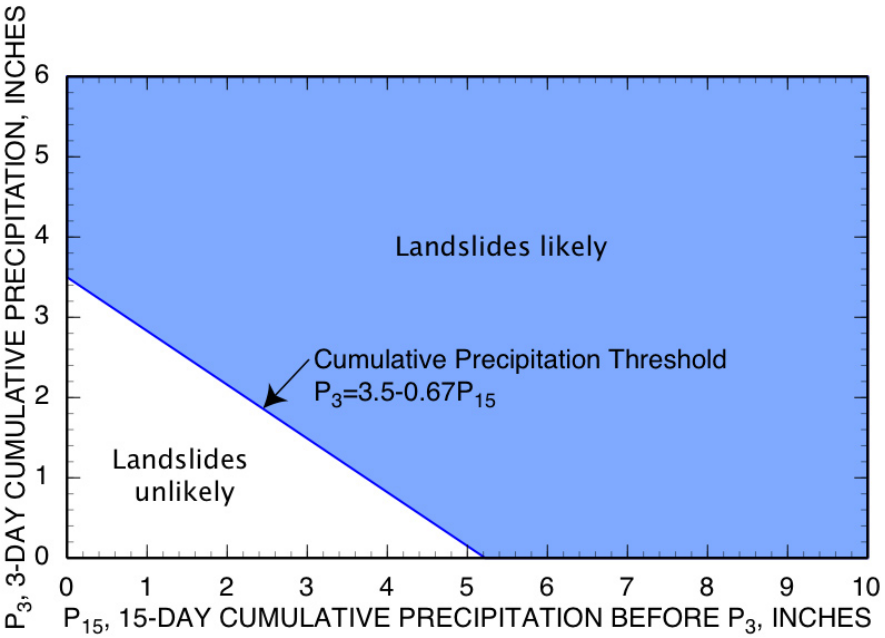

Figure 2. Cumulative Precipitation Threshold for Seattle, Washington, and surrounding areas. The cumulative threshold uses two variables, P_3, on the vertical axis, is the amount of precipitation that has fallen in the last 3 days; P_{15}, on the horizontal axis is the amount of precipitation that fell during the 15 days before the days of P_3. On days when precipitation amounts exceed the threshold (plot in the blue-shaded area of the graph) probability of landslide occurrence is about 10 percent. In a comparison of dates of 577 historical landslides between 1978 and 2003 with hourly rainfall records at Seattle's 17 rain gages, landslides occurred on about 10 percent of days when the threshold was exceeded at one or more gages.

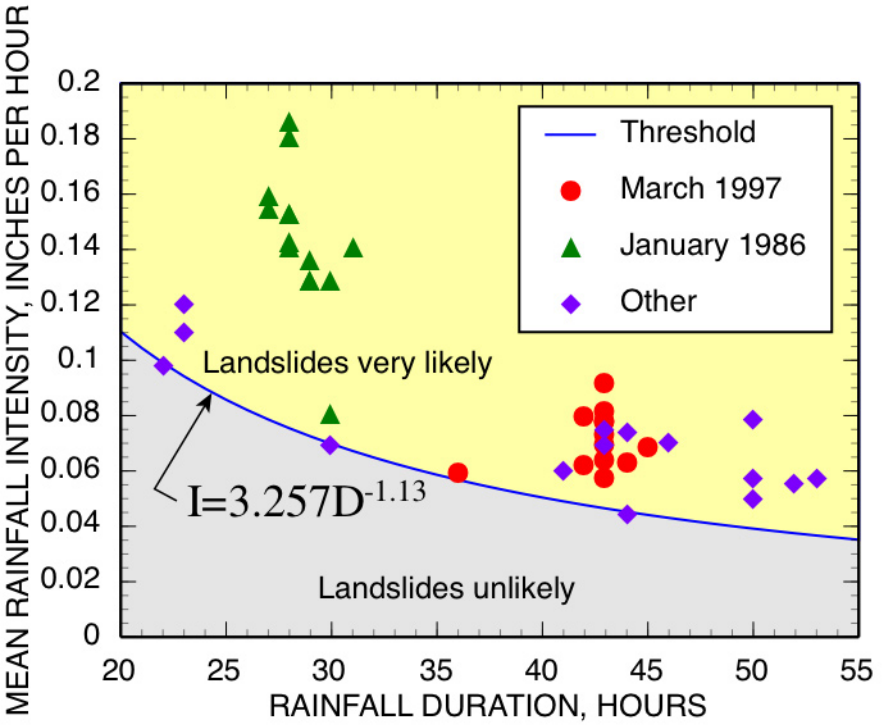

Figure 3. Rainfall intensity and duration threshold developed for Seattle, Washington, and surrounding areas. In this threshold (blue line), the intensity is the average rate at which rain has fallen since the beginning of a storm, and the duration is the amount of time that has passed since the beginning of the storm. Symbols on the graph show conditions that have produced historical landslides. On days when rainfall exceeds the threshold (plots above the blue line) probability of landslide occurrence is at least 30 percent. In a comparison of dates of 577 historical landslides between 1978 and 2003 with hourly rainfall records at Seattle's 17 rain gages, landslides occurred on about 30 percent of days when the threshold was exceeded at one or more gages. Landslides occurred on about 40 percent of days when the threshold was exceeded at 3 or more city rain gages and on 70 percent of days when the threshold was exceeded at 10 or more gages and antecedent soil wetness was high.

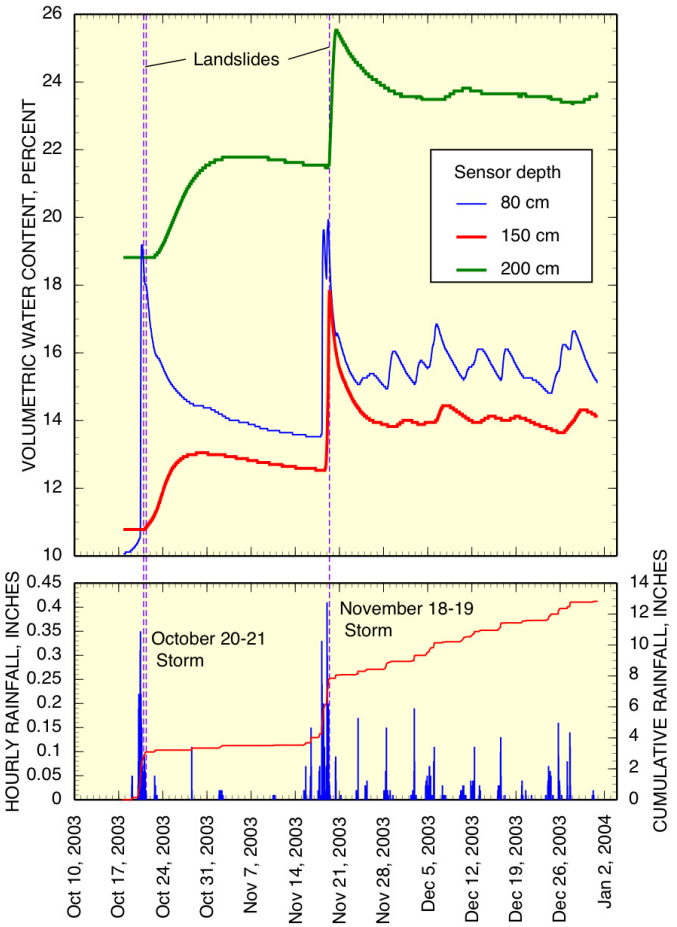

Figure 4. Instrumental monitoring of soil moisture conditions indicates when recent rainfall has made hillsides more susceptible to landslides. These graphs show that soil was very dry in early October 2003. Despite record-breaking rainfall, the October 20–21 storm produced a few landslides and the November 18–19 storm produced only one. The October and mid November rainstorms wetted the soil and later storms in November and December helped keep the soil wet and susceptible to shallow landslides.

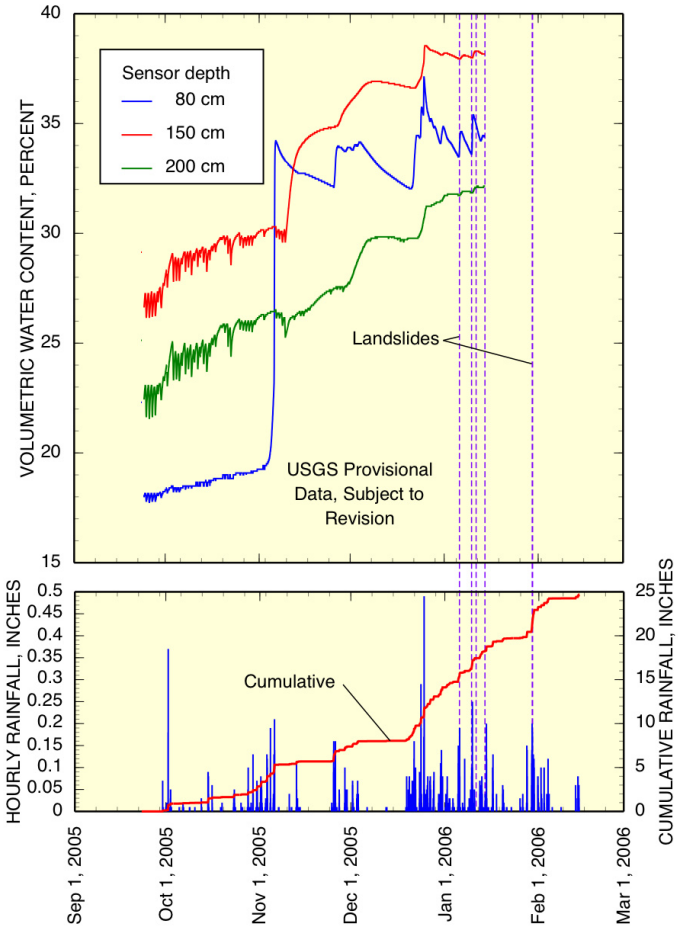

Figure 5. Rainfall during autumn 2005 began rewetting soil after the summer dry season. The extended rainy period from late December 2005 to early February 2006, further wetted the soil to depths of 2 meters (6 feet). Rainfall amounts of 1–2 inches in 24 hours induced landslides on January 6, 10, and 30, but we are unaware of any landslides triggered by intense rainfall on December 25. Landslides also occurred on other days, including one on January 14 at our monitoring site north of Edmonds, Washington.

pressure indicates when area hillsides are most susceptible to landslides (fig. 4 and 5).

Do the thresholds work elsewhere around Puget Sound?

The thresholds are considered more reliable in the western parts of Pierce, King and Snohomish Counties (from Tacoma to Everett) than in adjoining areas based on geologic and rainfall conditions. Until data become available to test and refine the rainfall thresholds for adjoining areas, the thresholds can be used as provisional guidance for forecasting landslides in Kitsap and Island Counties, the northern part of Thurston County and the eastern part of Mason County. Additional data and research would be required to develop landslide thresholds for other parts of Washington (or for other parts of the United States, as well).

What about false alarms?

Some storms that exceed the thresholds might not cause landslides, but the thresholds help people know when to be prepared for landslides.

What can be done in the future to improve landslide forecasts?

Reporting of landslides when they happen to local officials or the USGS can aid research to verify which storms produce landslides so that forecasts can be improved. Research has also shown that instrumental monitoring of soil conditions is the most accurate indicator of when the soil is wet enough to be susceptible to landslides; thus monitoring can improve landslide forecasts (fig. 4). Computer models are also being developed to improve landslide forecasts.

How can I prepare for landslides?

Prior to Storms:

1. Make sure your property complies with city or county guidelines and regulations governing storm-water discharge and hillside improvements, planting, and maintenance. Buildings should be located away from steep slopes.

2. Contact your local authorities to learn about the emergency-response and evacuation plans for your area. Develop your own emergency plan for your family or business.

During a Storm:

1. Stay alert! Many landslide fatalities occur when people are sleeping. Listen to the radio for warnings of intense rainfall. Be aware that intense bursts of rain may be particularly dangerous, especially after longer periods of heavy rainfall and damp weather.

2. If you are in an area that is susceptible to landslides (or has been subject to landslides in the past), consider leaving if it is safe to do so. Remember that driving during heavy rainstorms can be hazardous.

3. Listen for any unusual sounds that might indicate moving debris, such as trees cracking or boulders knocking together. A trickle of flowing mud or debris, tilting trees, open cracks, settlement, or other signs of ground disturbance may precede landslides. Be prepared to move quickly. Don't delay! Save yourself, not your belongings.

4. Be particularly alert when driving. Embankments along roadsides are particularly susceptible to landsliding. Watch the road for collapsed pavement, mud, fallen rocks, and other landslide dangers.

5. Be aware that strong shaking from earthquakes, which are known to occur in the Puget Sound area, can induce landslides or intensify the effects of landslides.

Where can I get more information?

To see current Outlooks,

http://landslides.usgs.gov/advisories/

To learn more about landslides and landslide thresholds,

http://landslides.usgs.gov

http://www.dnr.wa.gov/geology/

http://pubs.usgs.gov/of/2006/1064/

http://pubs.usgs.gov/of/2003/ofr-03-463/

http://pubs.usgs.gov/of/2000/ofr-00-0469/

Puget Sound area landslides and local weather,

http://www.ecy.wa.gov/programs/sea/landslides/

http://www.wrh.noaa.gov/sew/

Also Contact:

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